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Sex differences in visual-spatial ability: Components of cognitive processing

Susan Loring-Meier

SEX DIFFERENCES IN VISUAL-SPATIAL ABILITY:

COMPONENTS OF COGNITIVE PROCESSING

A Thesis

Presented to the

Faculty of

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San Bernardino

In Partial Fulfillment

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Master of Arts

in

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ABSTRACT

A large body of literature examining sex differences in various cognitive abilities indicates that males have an advantage in spatial perception tasks, with a very large effect size (d=.94) for mental rotation tasks. Social theories emphasize the impact of the sex-typed toys and play experiences of children, gender stereotyping in education, and the effect of practice and training on spatial ability. Biological theories emphasize the influence of hormones and brain organization on cognition. Biosocial theories reflect interactionist perspectives that involve an interrelationship of environmental and genetic influences. Evolutionary theories interpret sex differences in cognition in terms of sexual selection. This study proposes a cognitive process model in which cognitive tasks can be examined through separate sequential stages that are used to process the task at hand. Four individual tasks were administered to 48 college students (24 females and 24 males) recruited from a southern California university: An image generation task, an image maintenance task, an image scanning task, and an image rotation task. Results

indicated a male advantage for reaction time in all four tasks, with no difference in error rates between females and males.

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CHAPTER ONE

Introduction

Research has shown that sex differences exist in various areas of cognition. These differences are found in specific patterns of ability (Halpern, 1992; Kimura, 1996). It is well documented in the literature that women perform better on average than men on verbal fluency tasks such as anagrams, synonym generation, and spelling, and also on reading comprehension, and computational tasks (Halpern, 1992; Hyde, Fennema, & Lamon, 1990). Other areas in which females show an advantage are perceptual speed and scanning tasks, object location, memory for object location (Eals & Silverman, 1990; Kimura & Hampson, 1994), fine motor skills (Hampson, 1990), and decoding nonverbal communication (Hall, 1995). The only type of verbal task in which males outperform females is solving verbal analogies (Halpern, 1992). These findings show a female advantage in some areas of verbal, quantitative, perceptual, and general cognition.

Research has shown that a consistent male advantage exists in some types of visual-spatial performance and these findings have remained robust over the past twenty years

(Halpern, 1992; Linn & Peterson, 1986; Maccoby & Jacklin, 1974). Spatial perception, which is one type of visual-spatial task, involves identifying a horizontal or vertical position of a line or rod while ignoring distracting information (Halpern, 1992). Measures used to assess ability in spatial perception include tests such as the rod and frame task, which requires subjects to determine the vertical or horizontal position for a rod placed inside a tilted frame, and Piaget's Water Level Test which requires subjects to determine the angle of the water level in a tilted glass. Performance scores of males on this task have been consistently above those of females (Robert & Ohlmann, 1994). Linn and Peterson (1985, 1986) found a male advantage in performance on spatial perception tasks with an effect size of .64. However, there are conflicting findings regarding spatial performance of subjects who are more familiar with the laws of physics. Robert and Harel (1994) found the male advantage to occur among university architectural and physics students, yet Hammer, Hoffer, and King (1995) found no difference in performance scores of male and female architectural students.

Mental rotation is a second component of visual-spatial tasks in which males consistently outperform females. These results are reliably found on tasks that require transformations in visual working memory (Halpern & Crothers, 1995) such as the ability to rotate a stationery figure to imagine the figure from a different angle, or to imagine the folded or unfolded appearance of an object (Halpern, 1992). The male advantage has been a reliable finding in this specific area of visual-spatial ability with little fluctuation, and this is among the largest sex differences documented in the literature (Halpern, 1989). The average effect size in mental rotation tasks (.94, see Linn & Peterson, 1985; 1986) is so large and so robust that tests of statistical significance are often unnecessary (Cohen & Cohen, 1983; Masters & Sanders, 1993). Other visual-spatial areas showing a male advantage include spatiotemporal or dynamic spatial reasoning tasks, which involve tracking or judging the time of impact of an object in motion, with males showing higher accuracy scores than females (Law, Pellegrino, & Hunt, 1993).

Theories

Various theoretical positions attempting to explain the etiology of the sex differences in these cognitive abilities have been presented in the literature. The theories range from social to biological and include a variety of hypothesized interactions between them (see Maskie-Taylor, 1993, for a review). Biological perspectives include differences in brain size, brain organization, handedness (which reflects brain organization), prenatal stress, and nutrition. Social perspectives include home environment, occupation, gender stereotyping, self concept, and differences in the amount and type of experiences that females and males encounter.

The Role of Experience

Early Childhood. It has been suggested that sex differences in spatial ability reflect a differential amount of related experience between girls and boys. From early childhood, gender stereotyping influences the kinds of toys that girls and boys are provided for play; beliefs about what is appropriate for girls or boys are resistant to change (Crawford, Chaffin, & Fitton, 1995). Boys are provided with science-related toys, building equipment, puzzles, and objects that are designed to take apart and reassemble much more often than girls are provided them. Studies examining attitudes of college students about gender-appropriate toys for children indicate that Tinkertoys, blocks, and airplane models were more suitable for boys and tea sets, doll houses, supermarkets, and toy telephones were more suitable for girls (Miller, 1986). The play experiences of children have been related to later differences in spatial ability (Crawford et al., 1995). Practice using stereotypical masculine toys has been shown to be a predictor of visual-spatial ability in both girls and boys as well as the occupation of their mothers and the level of education of their fathers (Serbin, Zelkowitz, Doyle, & Gold, 1990).

Education. In a recent study examining performance on spatial tasks, Alyman and Peters (1993) found that males had an advantage over females in only two out of nine spatial tasks. However, these differences disappeared when females and males who had taken a greater number of math courses were compared. Studies have shown that children begin to believe that science and math are male domains and women are inferior to men in these areas as early as the third grade (Boswell, 1985), but the disparity in achievement level between females and males does not appear until high school when courses taken are a matter of personal choice. These findings suggest that gender stereotyping may have an influence on students' choices of what classes to take in high school and college, and may be a possible factor contributing to females enrolling in fewer math and science courses than males.

Research on gender differential treatment in the classroom has shown that males receive more attention overall, but especially in math and science classes (Eccles, 1989; Sadker & Sadker, 1994). Females experience a loss of confidence when they reach high school, even though their academic performance scores have been higher than males' scores through the pre-high school years and remain higher in all courses (Halpern, in press). These attitudes play an important part in the number of math and science courses taken in high school. The number of math and science courses taken, as well as spatial skill, has been shown to affect scores on the SAT-M which is a qualifier for entrance into advanced training in math and science careers (Bohlin, 1990; Casey, Nuttall, Pezaris, & Benbow, in press; Lubinski & Benbow, 1994). According to Dawis and Lofquist (1993), vocational choices are a function of preferences as well as ability, and males tend to make academic choices more congruent with math and science careers than do females, leading to a greater number of males in those careers (Lubinski & Benbow, 1992).

Practice Effects and Training. According to Baenninger and Newcombe (1995), appropriate environmental input is essential to the development of spatial and mathematical skill. The particular types of input necessary for development of optimal performance are more common in boys' experiences than in that of girls, showing a correlation between type and amount of environmental input and spatial ability. In a study by Law, Pellegrino, & Hunt (1993) examining gender differences and the effect of experience in dynamic spatial tasks, significant gender differences were observed for relative velocity judgments and these were related to prior experience with video games. The performance of both females and males improved equally as a result of feedback, suggesting that experiential history is associated with spatial performance. Further research conducted examining the effect of video game practice on spatial skills has shown a clear improvement in performance scores for both girls and boys with increased practice (Subrahmanyam & Greenfield, 1994). The effects of practice were greater for those children with lower levels of performance initially, but girls did not improve more than boys. This is an important finding because it adds to the large body of literature showing a consistent male advantage in certain spatial abilities that remains stable across post-pubescence samples (Voyer, Voyer, & Bryden, 1995). In a study of older adolescents, video game practice effects were measured using a game called Tetris which requires the ability to mentally represent shapes in different orientations and also to visualize the result of placing the shapes into specific openings in a pattern. Results indicated that playing Tetris reduced the time needed in mental rotation tasks as well as spatial visualization time (Okagaki & Frensch, 1994).

In a meta analysis of spatial ability and training studies, Baenninger and Newcombe (1989) found that the magnitude of improvement after general and specific training ranged between .51 and .67 in effect size. These findings lend support to the position that spatial ability is correlated with practice in spatially oriented experiences. Thus, there is a significant body of evidence showing that the type and number of spatial experiences affect the preferences and choices one makes which, in turn, have an incremental effect on the development of spatial ability.

Biological Theories

On the nature side of the etiological debate, biological theories can be divided into perspectives examining the influence of hormones and brain organization (Kimura, 1992; 1996; Levy & Heller, 1992; McKeever, 1995). Numerous studies have shown that hormonal influences on the developing brain have an effect on cognition and behavior (Allen, Richey, Chai, & Gorski, 1991). In female and male subjects of several species from rodents to primates, high levels of androgen during critical periods of development are associated with male-typical sexual behavior and learning behavior (Berenbaum, Korman, & Leveroni, 1996).

Performance of female rats injected with masculinizing hormones during critical developmental periods has been shown to equal that of males in radial-arm maze learning, and is superior to normal females and neonatally castrated males (Williams & Meck, 1991). In a study examining spatial ability in human females diagnosed with congenital adrenal hyperplasia (CAH), it was found that the CAH girls who had been exposed to abnormally large quantities of adrenal androgens in the prenatal or neonatal stages of development were superior to their unaffected sisters on several spatial ability measures that consistently show a male advantage. No other differences were found between the two groups on any other measures of verbal or reasoning ability (Collaer & Hines, 1995; Hampson, 1995; Resnick, Berenbaum, Gottesman, & Bouchard, 1986). These studies suggest hormonal influence on brain structures, cognition, and behavior. Hormones having this type of influence during critical developmental periods are termed "organizational" due to the production of permanent changes in the organization of the brain and the subsequent related behavior.

Further studies have investigated organizational hormone level and spatial capability and found that there seems to be separate optimal levels for women and men that relate to maximum spatial performance (Kimura, 1996; Nyborg, 1990; Shute, 1983). In a study by Gouchie and Kimura (1991) examining effects of testosterone (T) levels on spatial and nonspatial cognitive abilities in women and men, it was found that men with lower T levels performed better than other groups on spatial tasks which normally show a male advantage, and women with high T levels scored higher than low-T women on the same measures.

In addition, other studies of hormonal influence on behavior have investigated the influence of estrogen levels across the menstrual cycle in females. The findings show that women perform better on spatial tests in the low estrogen phase of the cycle, but better on verbal and fine manual tasks in the high estrogen phase of the cycle (Hampson, 1990; Kimura, 1996; Kimura & Hampson, 1994). In another study (Christiansen, 1993) of the relationship between circulating sex hormones and cognitive abilities in !Kung San men , a hunter-gatherer tribe of Namibia, serum testosterone was found to exhibit a positive relation to spatial abilities, and was negatively correlated with verbal fluency. In addition, testosterone levels were also positively correlated with field independence. Field independence is a term relating to the ability to perceive underlying visuospatial relations in a distracting and conflicting context (Witkin, Dyk, Faterson, Goodenough, & Karp, 1974). These results are indicative of an optimal level of androgen for maximum visual-spatial ability resting in the low male range (Kimura, 1996).

A second biological perspective related to the hormonal influence theory recognizes the importance of cerebral hemisphericity. Those advocating this position assert that there are lateral specializations of the cortex for cognitive processing of verbal and spatial material, with males showing greater asymmetry and females showing a more bilateral organization (Halpern, 1992; 1996). This perspective relates to hormonal influence in that it is suggested that the same hormones that influence the physical differentiation of the sexes also affect the way female and male brains are organized (Halpern, 1992). In a study conducted by Gill and O'Boyle (1995), electroencephalographic recordings were taken from female and male subjects while they were mentally rotating circles and arcs. Males were more accurate than females in determining size matches and exhibited lateralized right frontal lobe activation in all conditions. Females showed bilateral activation in frontal and temporal regions. These results suggest a difference in brain organization for visual-spatial functions in males and females. However, evidence for this assertion is conflicting (McKeever, 1996). A recent study examined sex differences in visuospatial performance in subjects with and without right hemisphere stroke (Desmond, Glenwick, Stern, & Tatemichi, 1994). Results showed female stroke victims as disproportionately impaired in visuospatial functioning as compared to male stroke victims, suggesting that visuospatial functions may be represented more laterally in the right hemisphere in females, and bilaterally represented in males.

In the same vein, laterality has been examined by studies in which handedness was used as an index of dominance. Handedness is an indirect indication of lateralization of brain dominance which researchers believe is biologically determined due to the presence of asymmetrical hemispheric functioning at birth, and therefore cannot be attributed to experience (Coren, 1990; Witelson, 1989). The handedness theory asserts that left-handed people (sinistrals) are right-hemisphere dominant for motor abilities and are more bilateral in cognitive function than right-handed (dextral) people who are left-hemisphere dominant (Martinez, 1987). Research has shown a parallel between sex differences and handedness in cognitive abilities. Reading disabilities, precocious verbal ability (as measured on the SAT-V which contains many analogies), mathematical giftedness, and sinistrality are found more often in males than in females (Benbow, 1988; O'Boyle & Benbow, 1990).

Biosocial Theories

Interactional perspectives of the etiology of spatial ability include theories which involve an interrelationship of environmental and genetic influences. Studies by Plomin (1989, Plomin & Neiderhiser, 1992) have provided evidence that genetic factors contribute to the variance of individual differences in the environment. "Variability in complex behaviors of interest to psychologists and to society is due at least as much to environmental influences as it is to genetic influences" (Plomin, 1989, p. 105).

In the same vein, the "bent twig" theory proposed by Casey and Brabeck (1995) asserts that biological factors predispose an individual to develop certain abilities and the environmental influences increase growth in the direction of the "bend" (Casey, 1996). Casey describes four systems that interact with genetic predispositions in spatial ability as conceptualized by Brofenbrenner (1989). The first is a microsystem of face-to-face interactions such as the home and school environments, which when considered in their effect on cognition, work to encourage or discourage spatial skill (or other types of cognitive skill). The second system is a mesosystem involving interconnections between at least two microsystems that work as reinforcing factors, producing gender-stereotyped behaviors. A third system is an exosystem which is comprised of microsystems excluding the developing person that exert a longitudinal influence such as former generations of the maternal family. Finally, the macrosystem includes beliefs and values within the lower systems that converge into a culture or subculture, such as a lack of provision for cross-gender typed experiences that enhance spatial ability. These social systems combine with biological influences and create a biological/environmental interrelationship (Wachs, 1992).

Evolutionary Theories

The biological/environmental interrelationship can also be explained in an evolutionary perspective based on sexual selection (Eals & Silverman, 1994; Geary, 1996). In a recent study examining spatial abilities of females and males, Silverman and Eals (1992) demonstrated that females consistently scored above males in recall of object location in a spatial array. When further studies examined recall without verbal labels of the objects, the female advantage remained consistent (Eals & Silverman, 1994). According to the theory proposed by Eals and Silverman, sex differences in spatial abilities developed through evolutionary forces as a result of division of labor in early hunter-gatherer societies. The theory asserts that spatial abilities showing a male advantage such as map reading, maze learning, and mental rotation correspond to those necessary for skillful hunting, while the female advantage in location recall of objects in a spatial array correspond to foraging for edible plants (Silverman & Eals, 1992).

Another biosocial theory introduced by Geary (1995) suggests that there are biologically-primary cognitive abilities, such as language, which are directly shaped by evolutionary history, and are universal. These primary abilities are developed in the natural contexts of play and social activities. In contrast, there are biologically-secondary abilities which are found only in technologically developed societies and must be taught in formal settings such as schools. According to Geary, the primary ability of habitat navigation, having developed more highly in males over the course of human evolution, is available for use in secondary tasks such as high school geometry and mental rotation tests. The female advantage in verbal fluency is related to the evolutionary development of greater primary cognitive systems that support language.

A Cognitive Process Model:

Components of Spatial Ability

A cognitive process theory has been suggested in which cognitive tasks can be examined from a perspective of the sequential stages one uses to process the task at hand (Halpern & Crothers, 1995; Halpern & Wright, 1996). In tasks reflecting a female advantage (verbal fluency and computational), rapid access to information stored in long-term memory and subsequent retrieval is required, whereas tasks showing a male advantage (visuospatial, spatiotemporal, and verbal analogies) require maintenance and transformations of mental representations in working memory. Therefore, the underlying processes used in executing a task may be the key to understanding sex differences in cognition.

Using the perspective of componential processes involved in mental imagery tasks, a recent study examined four aspects of visual mental imagery: image generation, image maintenance, image inspection, and image transformation (Dror & Kosslyn, 1994). Each of these tasks also varied in level of complexity. In image generation, subjects were required to create visual imagery in a pattern in short term memory, and this is called a visual buffer (Kosslyn, 1980). Image maintenance was defined as the ability to retain images over time in short term memory. Image scanning was the shifting of attention over a mental pattern, and image transformation was the rotation or other mental modification of the imaged pattern. In this study, Dror and Kosslyn compared young adult and elderly subjects on four tasks that separately examined each of the four aspects of mental image processing in order to discover the effects of aging on these processes. Their findings indicated that individual imagery processes are selectively affected by aging.

Building on the procedures for separating visual-spatial thinking into four different aspects, it is the purpose of the current study to examine these four separate processes as individual components in females and males to discover whether sex differences are associated with these four processes.

Hypotheses

If the distinction among the cognitive processes is correct, then it is hypothesized that sex differences will vary as a function of the underlying processes. 1)We expect that females will outperform males in the image generation task because this task requires retrieving information about that image from relatively long term memory. The literature has shown that females excel in accessing and retrieving information from memory (Halpern & Crothers, 1995). 2)The image maintenance task could show an advantage in the male direction because the literature shows a male advantage in using images in working memory. However, we are less confident in this prediction because there are differences between tasks that have no direct comparison in the literature. 3)The literature on image scanning is smaller than for the other imagery components, but based on Silverman and Eals' (1992) results showing females' superior memory for object location in a visual array, a female advantage is predicted. 4)Finally, it is hypothesized that males will outperform females in image rotation due to the large number of studies showing a clear male advantage in manipulation of mental images. Transformation tasks are conceptually similar to maintenance tasks in that they require holding a new image in a visual buffer in order to mentally modify it. The male advantage in mental rotation is robust and increases with increased complexity. Each of the tasks in the current study will contain varied levels of complexity. It is predicted that sex differences will be largest and most consistent with greater complexity due to the literature suggesting that sex differences become greater as a function of task complexity (Halpern, 1992; Okagaki & Frensch, 1994; Petersen & Crockett, 1985).

CHAPTER TWO

Method

Participants

Following Cohen's (1983) power analysis guidelines for large effect sizes, it was determined that six participants were needed for each of the eight conditions in the current study (sex by complexity for each of four tasks). Participants were 48 adults (24 females and 24 males) with an age range of 18 to 48, selected randomly from a southern California university by posting requests for volunteers on campus bulletin boards and by direct verbal communication.

Measures

The four computer tasks were administered in a DOS-environment via the Micro Experimental Lab (MEL) program. Participants responded to stimuli on the computer screen by pressing one of two keys with the index finger of their dominant hand. The stimuli developed by Dror and Kosslyn (1994) for use in previous research on mental imagery and aging were used. The four sets of stimuli were developed to examine four different visual-spatial tasks: generating a visual image, maintaining an image, scanning an image, and rotating an image.

Procedure

The image generation, image maintenance, image scanning, and image rotation tasks were administered using a sex by complexity split-plot factorial design. Each task was comprised of at least two levels of complexity. Participants were tested individually and the order of presentation of the four tasks was counterbalanced. Participants read instructions for each task from the computer screen. Two practice trials were presented before each task to allow participants to ask questions and become acquainted with the procedure. Test trials began when participants indicated to the experimenter that they were ready.

Task 1: Image generation. This task initially required participants to memorize the appearance of ten uppercase block letters. Each letter appeared on the computer screen inside four brackets that formed a rectangular frame, with a lowercase script version of the same letter presented below the frame (see Appendix A). Each letter remained visible for as much time as needed and was repeated three times.

Following this, participants were shown the script letters on flash cards and the participants were asked to draw the corresponding block letter on a worksheet containing ten sets of empty brackets in order to facilitate encoding into long term memory. The ten block letters (C, F, H, L, U, G, J, O, P, and S) used by Kosslyn, Cave, Provost, and Von Gierke (1988) and Dror and Kosslyn (1994) were used. The letters C, F, H, L, and U have been classified as simple because they are comprised of three or fewer segments. The letters G, J, O, P and S have been classified as complex because they include four or more segments. The letters O and L were reserved for practice trials, leaving eight letters available for test trials.

An exclamation point first appeared on the screen to signal the start of each trial. When ready, participants pressed the space bar which presented a blank screen for 500 ms. Next, a lowercase script version of one of the letters (e.g., ℓ) appeared for 500 ms, followed by a 500 ms blank screen. Next, a set of four brackets forming a 2.6 x 3.2 cm rectangular frame appeared with an **X** mark measuring 0.6 x

0.6 cm appearing inside the frame. The location of the **X** within the frame varied over each of 64 trials. Participants then decided whether or not the uppercase block letter that corresponded to the script letter presented on the computer screen would have covered the **X** mark, if the uppercase letter were to have appeared in the brackets. Participants indicated their response by pressing one key to indicate "yes" (the "N" key covered with a sticker marked "Y") and another key to indicate "no" (the "M" key covered with a sticker marked "N"). Of the 64 trials, 32 were simple letters (8 presentations each of C, F, H, and U) and 32 were complex letters (G, J, O, and P). Each of the eight letters were presented four times with a corresponding **X** mark in a position that would have been covered by the letter, and four times with a corresponding **X** mark in a position that would not have been covered by the letter.

<u>Task 2: Image maintenance.</u> This task was a variation of the previous image generation task in that a similar experimental sequence occurred, but using stimuli that were different from the 8 letters in the generation task. Participants were asked to decide whether or not a geometric

pattern unrelated to language would cover the **X** mark inside the brackets. The geometric patterns were not memorized before the test trials began because the task was designed to access working memory rather than long term memory. Therefore, the presentation of the stimuli was very short (as compared to the stimuli in the image generation task) before the participant was asked to respond whether or not the **X** mark would be covered by the pattern.

There were 24 different shapes, eight in each of three levels of complexity. These stimuli consisted of shapes with one, two, or three vertical or horizontal bars with a constant width of 0.6 cm (see Appendix B). Forty-eight trials were presented. Half of the trials in each level of complexity were followed by **X** marks that would have been covered by the pattern, and half were followed by **X** marks that would not have been covered by the pattern. Twelve practice trials were presented before the test trials began, with four patterns at each of the three levels of complexity. Half of the patterns in each level were followed by an **X** mark that would have been covered by the pattern, and half of the patterns were followed by an **X** mark that would not have been covered by the pattern.

Task 3: Image scanning. In this task, participants were asked to view a 4.2 x 4.2 cm rectangular frame with each side comprised of six 0.7 x 0.7 cm squares (see Appendix C) until they could visualize it. One square on each of three sides of the frame was black and the rest of the squares were white. The location of the blackened squares along each side were varied. When ready, participants pressed the space bar, and a 0.4 cm arrow appeared for 50 ms inside the frame in one of eight different orientations (one per trial for 60 trials) ranging from the upright position of 0 degrees to 315 degrees, and varying in 45 degree increments. The arrow pointed to either a black square or a white square (target cell) and was positioned at one of three distances from the target cell: adjacent, 1.2 cm away, or 2.1 cm away. Half of the trials at each distance presented arrows that pointed to a black target cell, and half the trials presented arrows that did not. Of the 60 test trials, 20 represented the arrow at each distance from the target cell. After the arrow had been displayed for 50 ms, both the arrow and rectangular frame disappeared. Participants then indicated whether the arrow had pointed to a black square or not by pressing one key for "yes" and another key for "no." Twelve practice trials were presented before test trials began, with two displaying arrows at each of the three distances that pointed to a black square, and two at each distance that did not.

<u>Task 4: Image rotation.</u> This task required participants to decide whether or not a pair of two-dimensional figures (see Appendix D) were identical. The figure on the left was the reference figure, and the figure on the right was either identical or mirror-reversed. The position of the figure on the right was varied in four different levels of orientation: 0^0, 90^0, 135^0, or 180^0. The figures were comprised of two or three bars with a width of 0.6 cm, and a maximum overall size of 2.6 x 3.2 cm. A black square was filled in at the top of each figure to assist participants in comparisons of the pairs. A total of 64 test trials were presented, with 16 in each of the four levels of rotation. Half the figures (8) were identical after rotation and half (8) were mirror-reversed. Within

each set of eight trials, four of the figures were comprised of two bars, and four were comprised of three bars. Test trials began with an exclamation point appearing on the computer screen, as a signal to participants to get ready for each new trial. When ready, participants pressed the space bar and a blank screen appeared for 500 ms. Next, a pair of figures appeared, and participants indicated that the figure on the right was identical by pressing one key, or mirror-reversed by pressing another key. Sixteen practice trials were presented before test trials, with four trials presenting each condition.

CHAPTER THREE

Results

Data Analysis

Data were tabulated separately for females and males for each of the four imaging tasks: generation, maintenance, scanning, and rotation. For each task, a separate analysis of variance was conducted. Outliers were defined as response times greater than 2 standard deviations above the participant's individual mean. Outliers were replaced with the mean of that participant's remaining scores for that cell. A Pearson's correlation was computed for reaction time and error rate for males and females in each conditin in order to determine whether a speed-accuracy trade off had occurred. A Pearson's correlation was also conducted between tasks to determine whether similar processes between tasks could be inferred.

Image Generation

In order to test the hypothesis that females would outperform males in the 2 x 2 (sex by letter complexity) image generation task, an analysis of variance (ANOVA) was computed using the SPSS program. Results showed a main effect of gender [$F(1,47)=6.05$, $p < .05$, $d=0.67$] with reaction time for males (M=3025.36ms, SD=1391.29) significantly faster than reaction time for females (M=4192.67ms, SD=1901.39). There was also a significant main effect of complexity [$F(1,47)=49.69$, $p <.001$]. The gender by complexity interaction did not achieve statistical significance [$F(1,47)=.34$, $p >.05$]. Refer to Table 1 for means and standard deviations, and to Figure 1 for a graph of means by condition.

The error rate for females and males in both the simple and complex letter conditions were not statistically different [$F(1,47)= .76$, $p >.05$]. Refer to Table 2 for means and standard deviations, and to Figure 2 for a graph of means by condition. A Pearson's r was computed to determine whether or not there was an overall speed-accuracy trade-off, combining both the simple and complex letter conditions across gender [$r(24)=.13$, $p >.05$]. The correlation for females in the simple letter condition [$r(24)=.25$, $p >.05$] was very small, and the correlaton for males was the same as for females [$r(24)=.25$, $p >.05$]. In the complex letter condition, there was virtually no correlation between accuracy and reaction time for females [$r(24)=.07$, $p > .05$], or for males [$r(24)=.03$, $p > .05$].

Image Maintenance

In order to test the hypothesis that males would excel in the 2 x 3 (sex by number of pattern segments) image maintenance task, an ANOVA was computed. As predicted, the

Table 1.

Mean reaction time and standard deviations for image generation task.

Complexity	Females		Males	
	M	SD	M	SD
Simple	1815	824	1274	564
Complex	2376	1098	1750	912

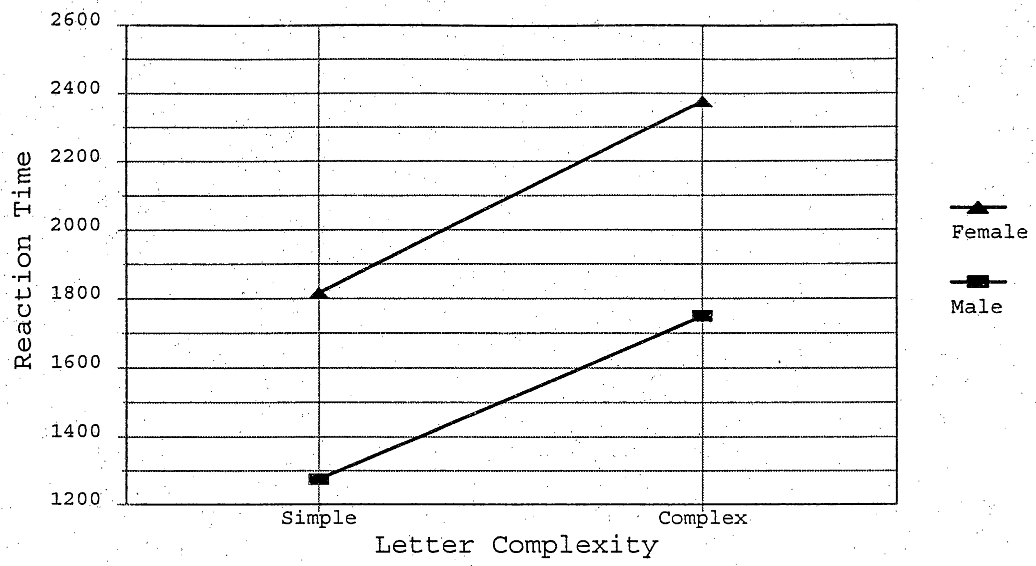


Figure 1. Mean reaction time in milliseconds for the image generation task.

Table 2.

Mean error rates and standard deviations for the image generation task.

Complexity	Females		Males	
	M	SD	M	SD
Simple	0.07	0.06	0.10	0.08
Complex	0.20	0.11	0.20	0.09

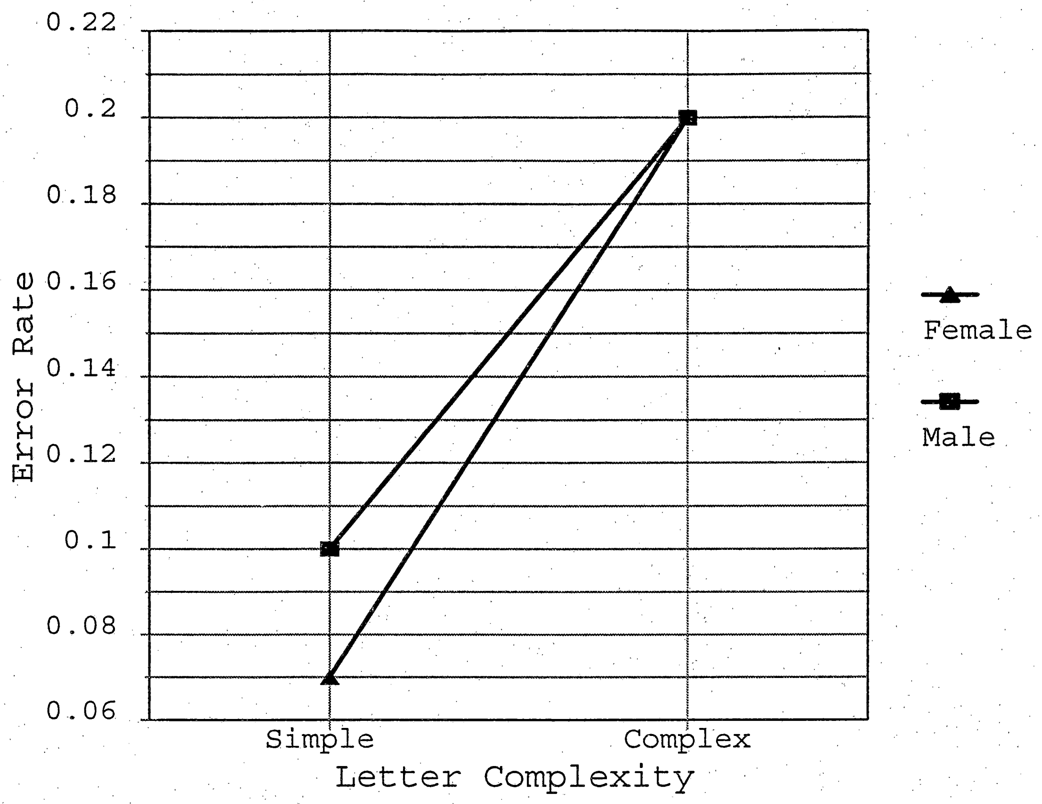


Figure 2. Mean error rates for the image generation task.

results indicated a main effect for gender [$F(1,47)=8.13$, $p < .05$, $d=0.77$], with males showing a significantly shorter reaction time (M=1251.61ms, SD=356.49) than females (M=1606.79, SD=495.24). Results also showed a main effect of pattern complexity [$F(2,92)=47.36$, $p < .05$], which was not moderated by gender [$F(2,92)=.86$, $p > .05$]. Refer to Table 3 for means and standard deviations by condition, and to Figure 3 for a graph of means by condition.

The error rates for males were not significantly different than for females in any of the three pattern complexity conditions [$F(2,92)= .37$, $p > .05$]. Refer to Table 4 for means and standard deviations by condition, and to Figure 4 for a graph of means by condition. The Pearson's r showed no significant correlation between speed and accuracy for males in the 1-segment pattern condition [$r(24)= .17$, $p > .05$] or for females [$r(24)= .07$, $p >.05$]. The correlation between speed and accuracy in the 2-segment condition was not statistically significant for males [$r(24)= .13$, $p > .05$] but was significant for females [$r(24)= .31$, $p < .05$]. The 3-segment condition showed no

Table 3.

Mean reaction time and standard deviations for the image maintenance task.

Complexity	Females		Males	
	M	SD	M	SD
1 Segment	1316	388	1026	253
2 Segment	1663	592	1303	381
3 Segment	1840	593	1424	527

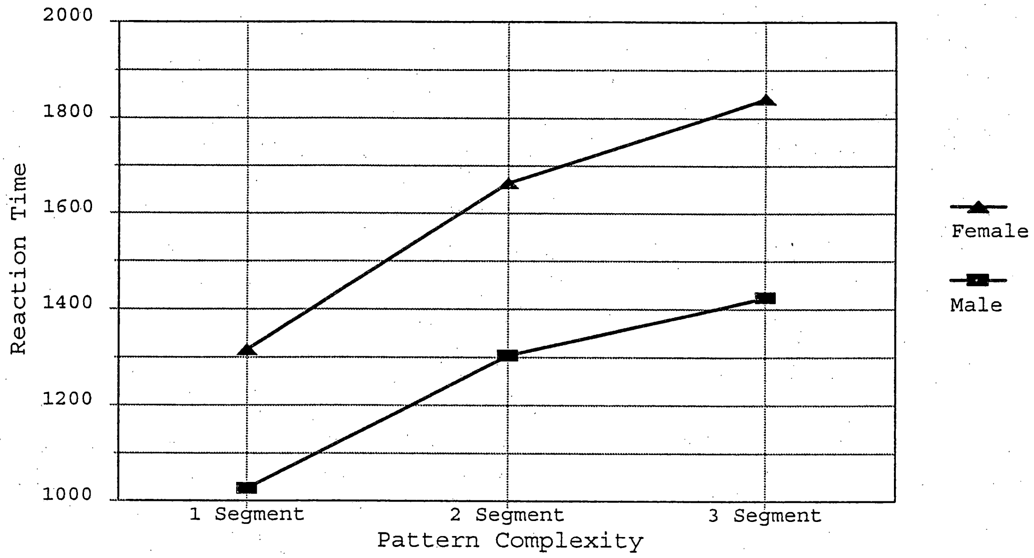


Figure 3. Mean reaction time in milliseconds for the image maintenance task.

Table 4.

Mean error rates and standard deviations for the image maintenance task.

Complexity	Females		Males	
	M	SD	M	SD
1 Segment	0.03	0.05	0.03	0.04
2 Segment	0.13	0.08	0.11	0.13
3 Segment	0.12	0.11	0.11	0.13

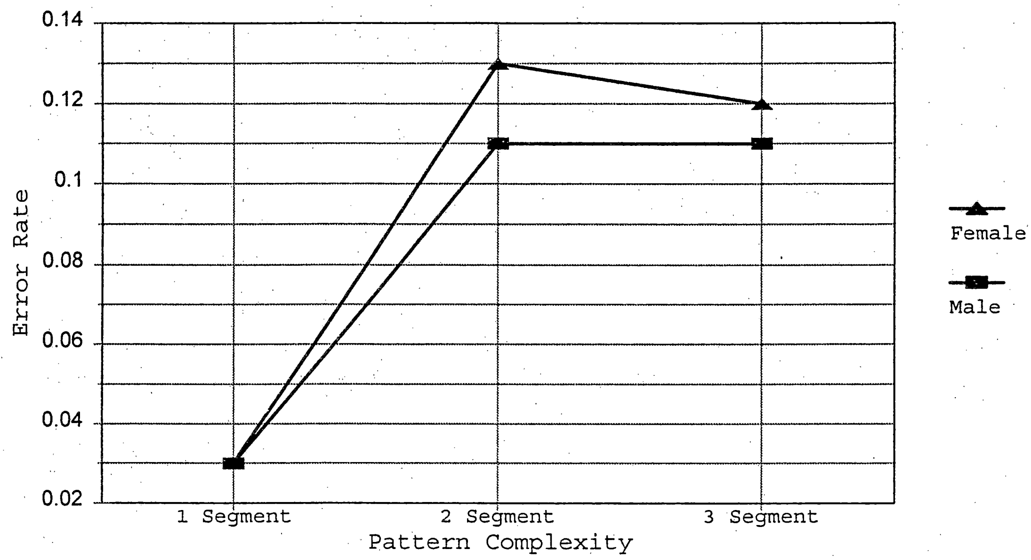


Figure 4. Mean error rates for the image maintenance task.

significant correlation for males [$r(24)=.10$, $p > .05$] or for females [$r(24)=.04$, $p > .05$].

Image Scanning

In order to test the hypothesis that females would have an advantage in the image scanning task, a 2 x 3 (sex by arrow distance) ANOVA was computed. The results indicated a main effect of gender [$F(1,47)=5.37$, $p < .05$, $d=0.63$] with males showing shorter reaction times ($M=850.11$, $SD=227.59$) than females ($M=989.46$, $SD=190.83$). A main effect of arrow distance was also found [$F(2,94)=11.30$, $p < .05$], but again, this effect was not moderated by gender [$F(2,94)=.84$, $p > .05$]. Mean reaction times and standard deviatons by condition can be seen in Table 5, and means are also presented in the graph in Figure 5.

The error rates for females and males were not statistically different [$F(2,94)=.05$, $p > .05$]. Mean error rates and standard deviations by condition can be seen in Table 6, and a graph of mean error rates appear in Figure 6.

The Pearson's r showed a significant negative correlation between response time and accuracy for males [$r(24)= -.48$, $p < .05$], indicating an increase in accuracy

Table 5.

Mean reaction time and standard deviations for the image scanning task.

Arrow	Females		Males	
Distance	M	SD	M	SD
Adjacent	919	172	812	201
1.2 cm	988	193	845	247
2.1 cm	1060	248	892	294

Figure 5. Mean reaction time in milliseconds for the image scanning task.

Table 6.

Mean error rates and standard deviations for the image scanning task.

Arrow	Females		Males	
Distance	M	SD	M	SD
Adjacent	0.04	0.06	0.03	0.03
1.2 cm	0.12	0.07	0.10	0.06
2.1 cm	0.11	0.06	0.11	0.05

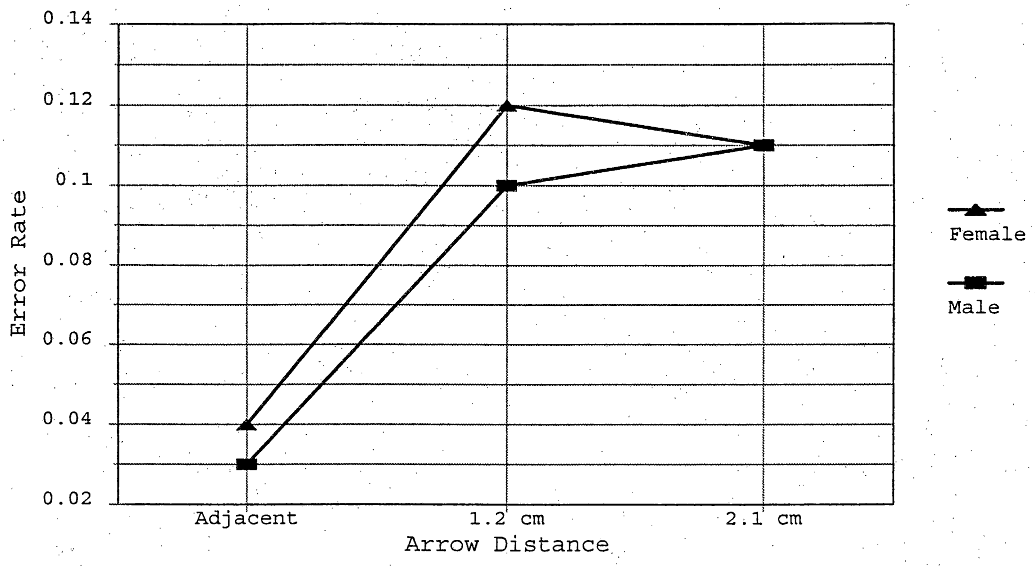


Figure 6. Mean error rates for the image scanning task.

with a decrease in reaction time for the adjacent arrow condition. Females showed no significant correlation [r (24)= .02, p > .05] in the adjacent arrow condition. In the 1.2cm arrow distance condition, the correlation between response time and accuracy was not significant for males [r(24)= .17, p > .05] or for females [r(24)= .32, p > .05]. The 2.1 arrow distance condition also reflected no significant speed- accuracy trade off for males [r(24)= .12, p > .05] or for females [r(24)= .10, p > .05].

Image Rotation

In a test of the hypothesis that males would outperform females in the mental rotation task, a 2 x 4 (sex by number of figure segments by degree of rotation) ANOVA was computed. As predicted, results indicated a main effect of gender [F(1,47)=7.09, p < .05, d=0.73] with males showing significantly shorter reaction time (M=2177.81ms, SD=819.70) than females (M=3035.59, SD=1348.62). A main effect was found for number of pattern segments [F(1,47)= 25.89, p < .05], however, this effect was not moderated by gender [F(1,47)= 1.51, p > .05]. A main effect of degree of rotation was also found [F(3,138)=71.11, p < .001], and this effect was moderated by gender [$F(3,138)=5.09$, $p < .01$]. The mean reaction times and standard deviations for each degree of rotation (collapsed across pattern complexity) appear in Table 7, and mean reaction times (also collapsed across pattern complexity) are graphed in Figure 7.

The error rates for females were not significantly different from males for any of the four degrees of rotation [$F(3,138)=.11$, $p > .05$]. Table 8 shows mean error rates and standard deviations for each of the four degrees of rotation. Figure 8 shows the graph of mean error rates collapsed across pattern complexity. The Pearson's r computed for the 0 degrees condition showed no significant correlation between speed and accuracy for males [$r(24)= .03$, $p > .05$] or for females [$r(24)= .04$, $p > .05$]. The correlation was also not significant in the 90 degrees condition for males [$r(24)= .02$, $p > .05$] or for females [$r(24)= .02$, $p > .05$]. The correlation in the 135 degrees condition showed no significance between speed and accuracy for males [$r(24)= .08$, $p > .05$] or for females [$r(24)= .03$, $p > .05$]. There was also no correlation between speed and

Table 7.

Mean reaction time and standard deviations for the image rotation task.

Degree of Rotation	Females		Males	
	M	SD	M	SD
0	2159	1328	1626	736
90	3055	1317	2282	841
135	2982	1086	2239	832
180	3806	1670	2559	997

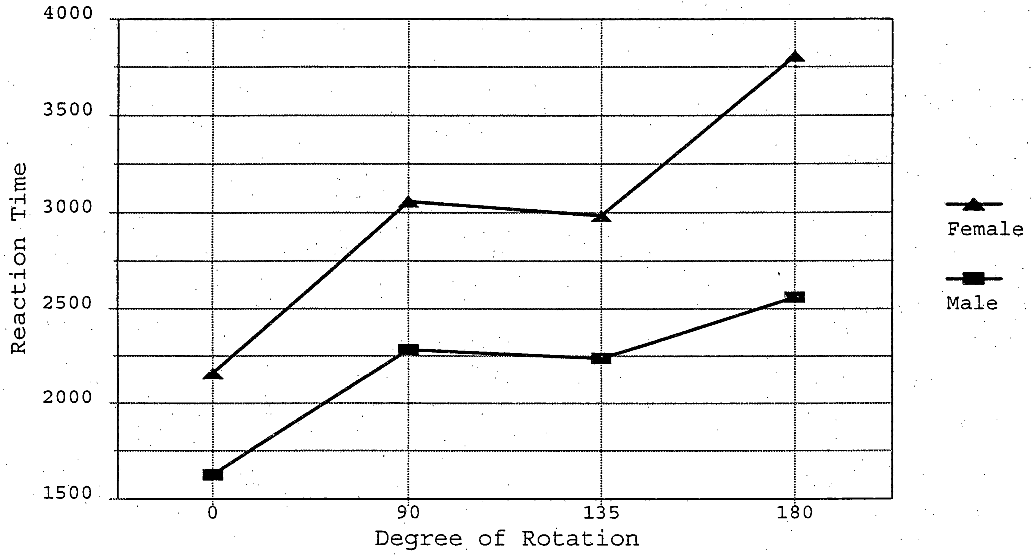


Figure 7. Mean reaction time in milliseconds for the image rotation task.

Table 8.

Mean error rates and standard deviations for the image rotation task.

Degree of Rotation	Females M	Females SD	Males M	Males SD
0	0.04	0.07	0.08	0.09
90	0.11	0.12	0.14	0.17
135	0.07	0.12	0.11	0.14
180	0.13	0.10	0.11	0.14

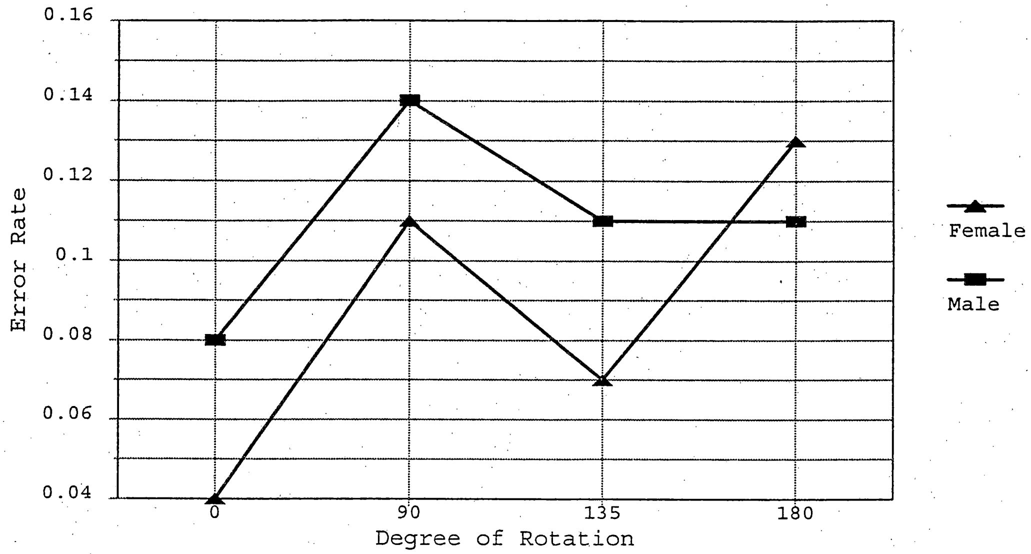


Figure 8. Mean error rates for the image rotation task.

accuracy for the 180 degree condition {males: [$\underline{r}(24) = .16$, $\underline{p} > .05$]; females [$\underline{r}(24) = .04$, $\underline{p} > .05$]}.

The Pearson's correlation between tasks revealed that all four tasks were significantly correlated at the 0.001 level. The image generation task was correlated with the the image maintenance task [$\underline{r}(48) = .71$, $\underline{p} < .001$], image scanning task [$\underline{r}(48) = .74$, $\underline{p} < .001$], and the image rotation task [$\underline{r}(48) = .60$, $\underline{p} < .001$]. The image maintenance task was also correlated with the image scanning task [$\underline{r}(48) = .62$, $\underline{p} < .001$], and the image rotation task [$\underline{r}(48) = .62$, $\underline{p} < .001$]. The image scanning task was also correlated with the image rotation task [$\underline{r}(48) = .52$, $\underline{p} < .001$].

CHAPTER FOUR

Discussion

For the image generation task, it was predicted that females would outperform males because the task involved the use of long-term memory to retrieve images of eight uppercase block letters. The cues for recall were lowercase script letters that had been previously memorized along with the accompanying uppercase block letter in the learning phase of the task. Due to the language-related nature of these images, the hypothesis followed the large body of literature showing that females have an advantage in most language-related tasks (especially those requiring retrieval from long-term memory), with the exception of verbal analogies (Halpern, 1992; Hyde, Fennema, & Lamon, 1990). In addition, the literature also shows females as having superiority in perceptual speed, object location, memory for object location, and in general, most tasks that involve accessing and retrieving information from long-term memory (Eals & Silverman, 1990; Halpern & Crothers, 1995; Kimura & Hampson, 1994).

Contrary to these findings, our results indicated that females performed with a longer reaction time (over 1 second) than males, with no differences in error rate. In reaction-time studies, a difference of over 1 second is theoretically important because it is a substantial difference in processing time. The additional time did not "pay off" in increased accuracy, as some researchers in hindsight have suggested (Goldstein, Haldane, & Mitchell, 1990). These results suggest that the image generation task was not a language-oriented task as previously categorized, but instead a spatial task which depended heavily on remembering the shape of the letters and then mentally fitting the **X** mark into that shape.

The letters were not used in the usual natural language context in this task. Several of the participants remarked during the experiment that this task reminded them very much of the computer game called "Tetris," which is a spatial task involving placing small two-dimensional shapes into similarly shaped openings. The literature shows males as having superior performance in video games (Law, Pellegrino, & Hunt, 1993; Subrahmanyam & Greenfield, 1994), and confirms the results obtained in the current study.

For the image maintenance task, it was predicted that males would excel because of the literature showing a male advantage in using images in working memory (Halpern & Crothers, 1995). Our hypothesis was supported. Males showed a shorter reaction time (1/3 sec.) than females, which translates into a large effect size, with no difference in error rates. This task differed from the image generation task in that the patterns were viewed only briefly before the participants were asked to make a timed decision as to whether or not the **X** mark would fit into the pattern area. This task clearly depended upon using a visual-spatial working memory to keep the image active long enough to permit a response. Both the image generation and the image maintenance tasks showed a difference in reaction time of 2/3 of a standard deviation, indicating a possible similarity between tasks in the cognitive components being used for each task, which appear to be the processes involved in visual-spatial working memory.

The a priori prediction for the image scanning task stated that a female advantage was expected because of the female advantage in memory for object location in a visual array (Silverman & Eals, 1992). This task was similar to the object location studies in that it involved scanning the image to find the location of the blackened squares. The hypothesis was not supported. The mean reaction time for males was shorter (1/3 sec.) than for females, with no difference in error rates.

These results may indicate further evidence that the task is relying on spatial ability processing factors rather than memory for location. The literature showing females' superiority in locating objects in a visual array refers to familiar objects (Silverman & Eals, 1992) rather than novel shapes and arrows without any inherent meaning. The scanning task in the current study used no familiar objects, only a set of rectangular frames that remained unchanged throughout all 60 trials except for the location of the blackened squares. It is also possible that males were able to respond faster because of their ability to rule out distracting information better than females (Halpern, 2, 1992) which may allow a quicker response due to a more narrow focus on the information presented.

The prediction for the image rotation task (sex by figure complexity by degree of rotation) that males would outperform females was supported. Males exhibited a shorter reaction time (7/8 sec.) than females, with no significant difference in error rate. In the current study, females have shown that their ability in mental rotation of two-dimensional images is at least as accurate as males even though females show a delayed response time. The literature shows large effect sizes for a male advantage in manipulation of mental images (Cohen & Cohen, 1983; Halpern, 1989; Linn & Peterson, 1985,1986; Masters & Sanders, 1993), but these findings relate to three-dimensional figures which are by their nature more complex and would show a significantly greater divergence for sex differences in rotation ability.

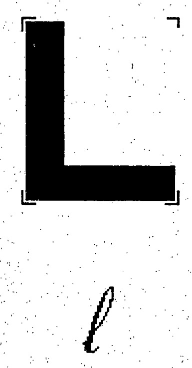
In view of the findings of the current study, it is clear that females show a delayed reaction time for spatial tasks. The gender difference in response time was found on all four of the visual-spatial tasks. Each task involved using different subcomponents of visual-spatial processing.

According to Kosslyn (1987), a sequential process is used to add each segment of a letter to an image separately.

This process is necessary because the location of the segments need to be compared with the location of the other segments in the image, and this cannot be achieved in one step. Both the image generation and the image maintenance tasks required spatial ability to evaluate the location of the **X** marks relative to the letter or pattern for each trial. It is possible that the faster reaction time for males in both of these tasks was due to a male advantage in breaking down images into individual components, and retrieving spatial information about those components. Dror and Kosslyn's (1994) findings indicate that processes used to add segments to an image differ from those used to scan or rotate an image. Mentally adding segments one at a time requires first breaking the image down into individual components, then analyzing the location of each separate component relative to all the others. This suggests that sequential processing of image segments may have a similarity to mental manipulation of images as in mental rotation tasks, but points to a type of manipulation that is distinct from rotation. Further examination of this possibility would be an interesting next step in understanding subcomponents of visual-spatial processing.

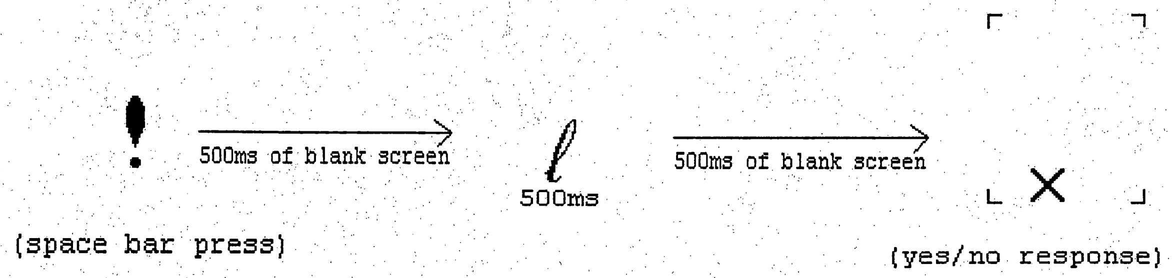
The Pearson's correlation of all four tasks suggests that similar cognitive processes were being used in each of these tasks. The results of the analyses of variance showing males responding faster than females on all four tasks suggest that it is the processes at which males excel that are being measured. Therefore, the logical conclusion that can be drawn is that visual-spatial working memory was the most salient process necessary to execute each of these tasks. Further examination of the ways that males and females differ in processing information is needed. This may be accomplished via the development of more sensitive cognitive measures that effectively isolate those differences.

Appendix A: Image Generation Task Stimuli



Example of a stimulus presented during

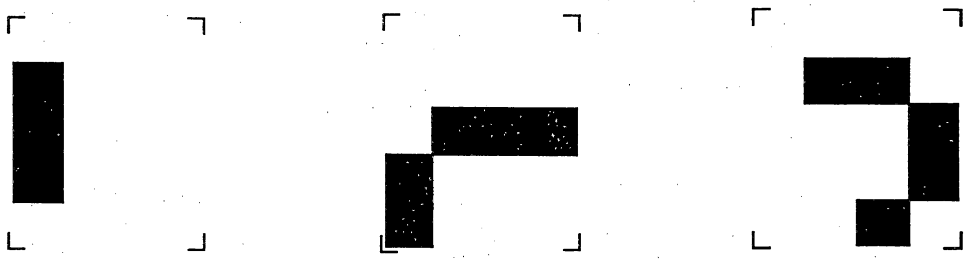
the learning stage.



Example of a trial sequence for the image

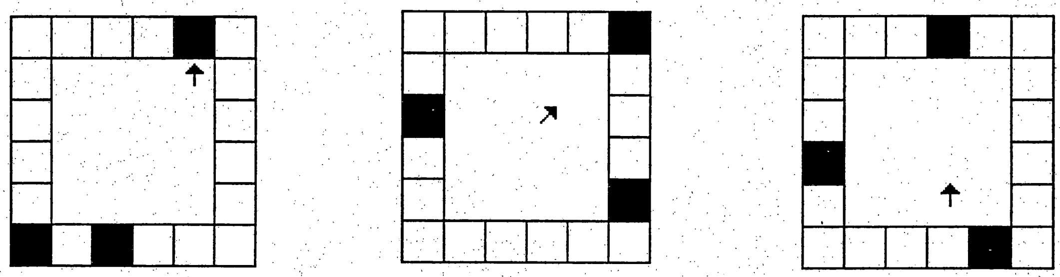
generation task.

Appendix B: Image Maintenance Stimuli

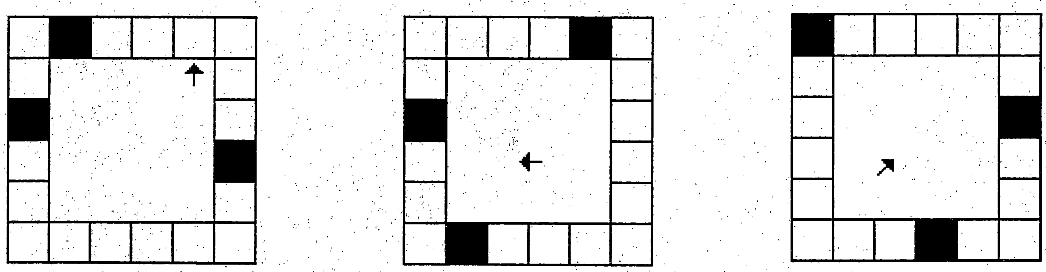


Examples of 1, 2, and 3 segment patterns.

Appendix C: Image Scanning Task Stimuli

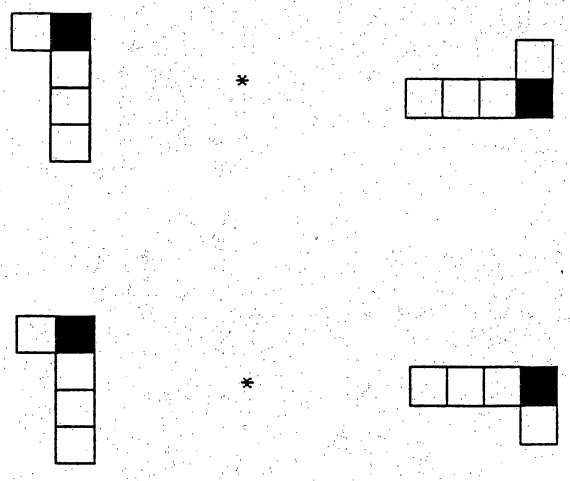


Example of arrow at 3 distances, pointing to black squares.



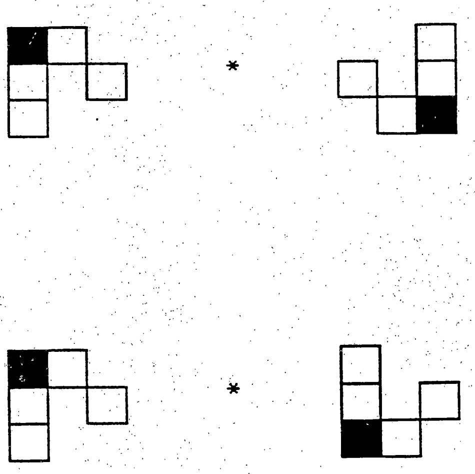
Example of arrow at 3 distances, pointing to white squares.

Appendix D: Image Rotation Stimuli



Example of identical and mirror-reversed 2-bar figures rotated 135^0 (above).

Example of identical and mirror-reversed 3-bar figures rotated 90^0 (below).



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